CONTROLLER-PILOT DATA LINK COMMUNICATIONS

Roadmap for Human Factors Activities

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Executive Summary

As part of a NAS Modernization Task Force Data Link Issues Team, the Federal Aviation Administration (FAA) and industry, recently agreed on a Controller-Pilot Data Link Communications (CPDLC) development and implementation path that proceeds directly to an aeronautical telecommunications network (ATN) CPDLC implementation. This path eliminates an early operational trial of an aircraft communications addressing and reporting system (ACARS)-based (non-ATN compatible) service that was expected to incorporate mitigation strategies for human factors risks. At its August 1998 meeting, the RTCA Free Flight Steering Committee endorsed the revised path but expressed concern that early and ongoing human factors work had not been effectively integrated into the current CPDLC path. The success of the CPDLC program depends on an integrated, timely, and structured human factors research and engineering process to effectively incorporate human-system performance considerations. This document was prepared as part of a series of activities to address the concern identified by the Free Flight Steering Committee and promote a coordinated government/industry strategy for CPDLC human factors risk mitigation.

To prepare this document, the FAA Aeronautical Data Link Integrated Product Team convened a human factors working group of approximately thirty FAA and industry representatives who have been active in the data link community. The working group assessed the status of data link human factors and identified over 50 reports, spanning a twenty year period, including recent reports on the Future Air Navigation System (FANS)/1 and the Preliminary EUROCONTROL Test of Air/Ground Data Link (PETAL) operational trials. In addition, the group noted two major FAA-industry efforts by the Society of Automotive Engineers (SAE) Human Behavioral Technology (G10) Committee and the RTCA Special Committee 169 (Data Link) that resulted in human factors guidance and requirements documents for air and ground systems.

While it is clear that both the FAA and industry have been actively working human factors data link issues for over two decades, recent developments and re-directions in the CPDLC program path result in the need for a re-direction of the associated human factors work. This report identifies where additional human factors activities are needed, where on-going programs should be re-directed or expanded, and lays out a roadmap or plan to ensure that human factors are adequately addressed in current and future Builds of CPDLC.

The recommendations of the working group are presented as a CPDLC human factors roadmap which consists of a set of activities and a timeline. Five activities were flagged as critical to the assessment of human performance and the mitigation of human factors risks in the current CPDLC path. These include the following:

1. Review and update human factors requirements and guidance

2. Test and evaluate Air Traffic Service Specialist (ATSS)[1]/ground system human-computer interface (HCI) and interaction
3. Test and evaluate pilot/flight deck HCI
4. Test and evaluate ATSS/pilot/system integration
5. Demonstrate ATSS/pilot/system integration

Within each of these areas, the roadmap proposes operational, product oriented research, analysis, and test and evaluation programs aimed at identifying and mitigating key risks associated with human-system performance in CPDLC. The proposed activities entail a series of iterative human factors studies, using partially and fully functional prototypes, and ultimately production system components, to progressively refine and validate system design, training, operations, and procedures requirements.

Activities

The five CPDLC human factors activities proposed in the roadmap are described below:

1. Review and update human factors requirements and guidance - Development of the human factors content for FAA CPDLC system specifications and advisory material, including Advisory Circulars (AC 20-DC and AC 120-COM), the Airman's Information Manual (AIM), training bulletins, and FAA Order 7110.65.
2. Test and evaluate ATSS/ground system HCI - Evaluation of prototype hardware/software (display system replacement [DSR]) to identify usability and CPDLC task integration issues, and validate and refine associated FAA guidance material.
3. Test and evaluate pilot/flight deck HCI - Evaluation of prototype hardware/software (e.g., American Airlines avionics) to identify usability and CPDLC task integration issues, and validate and refine associated FAA guidance material.
4. Test and evaluate ATSS/pilot/system integration - Operational tests of as much actual hardware/software as possible (ground, air, and system) supplemented by prototype equipment to run simulation trials and to identify issues associated with the interaction of controller/pilot operational communication procedures, controller team procedures, and flight crew procedures.

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1 ATSS is used to refer to all FAA air traffic service provider personnel who have a role in CPDLC operations. These personnel include controllers, air traffic supervisors, and airway facility system maintainers.

5. Demonstrate ATSS/pilot/system integration - Operational system demonstration using production airborne and ground hardware and software in a simulated operational environment to validate the effective interaction of controller/pilot operational communication procedures with controller team procedures, and flight crew procedures.

Timeline

To achieve full integration of human factors in CPDLC development, the context in which the activities are set is as important as the activities themselves. Therefore a major part of this roadmap is the sequence and dependencies among the human factors activities and other CPDLC development activities (see Appendix C for the integrated CPDLC schedule).
Figure ES-1 depicts the recommended human factors activities in the context of CPDLC development milestones.

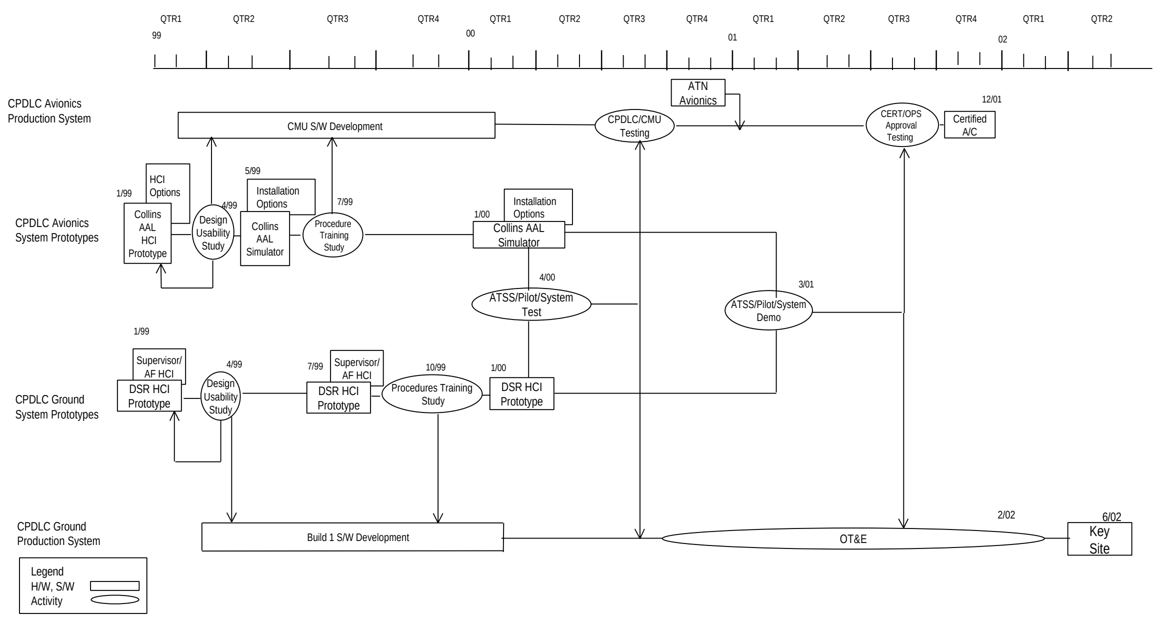

Figure ES-1. Recommended Human Factors Activities in Context of CPDLC Development Schedule

To affect the ongoing avionics and ground system development, the human factors activities should focus on an ATN-based CPDLC implementation and begin by early 1999. Several contingencies exist in the timeline. For example, a prototype of the planned American Airlines HCI must be either provided or developed in order to do a usability assessment of the system. A controller HCI study can leverage the William J. Hughes Technical Center (WJHTC) research prototype that will be available to assess the usability of the controller HCI.

The following are important dates in the timeline:

- January 1999 - initial draft of updated human factors requirements and guidance, including FANS and PETAL lessons learned.
- January 1999 - initial prototypes available of flight deck and ground system CPDLC HCI for usability studies.
- Late summer and early fall of 1999 - air and ground HCI's integrated into their respective workstations for task integration, procedures, and training studies.
- Early 2000 - simulation environment with linked air and ground simulators available for evaluation of ATSS/pilot/system integration in a full operational context (includes operational communication procedures, total system performance, and failure modes).
- Mid 2000 - 2001 - additional prototypes for HCI evaluations includes activities to validate alternative airline avionics implementations and evaluations of ground procedures and roles for supervisors and maintenance personnel.
- Starting December 2000 - an ATSS/pilot/system integration demonstration to test and validate the requirements and the results of previous human factors activities, using as many production system components as possible.

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Section 1

Introduction

Controller Pilot Data Link Communication (CPDLC) is a means of communication between controller and pilot, using data link for Air Traffic Service (ATS) communications (ICAO Annex 10, March 1998). The shift from a voice communications capability to a voice and data communications capability will enable fundamental changes in the way controllers and pilots communicate.

CPDLC is a primary building block for aeronautical data link, which, in turn, is a critical enabling technology for Free Flight capabilities. In the Free Flight Select Committee report, Government/Industry Operational Concept for the Evolution of Free Flight (RTCA, 1998) CPDLC was identified as a core capability for limited deployment (CCLD) under the Free Flight Phase 1 (FFP1) program. The goal of the FFP1 program is to operationally evaluate core capabilities at selected facilities for early user benefits by December 2002. In particular, the FFP1 operational evaluation is intended to assess and address two critical overarching risk areas: human factors and safety (RTCA, 1998).

During this same time period, a concomitant effort by the NAS Modernization Task Force Data Link Issues Team established a government/industry consensus on a CPDLC development and implementation path that proceeds directly to an Aeronautical Telecommunications Network (ATN)-based CPDLC implementation, eliminating an early operational trial of ACARS-based (non-ATN compatible) services. The RTCA Free Flight Steering Committee endorsed that path at its August 1998 meeting but expressed concern that "Human factors considerations that were to have been addressed early on by the originally proposed ACARS project would now be delayed beyond the FFP1 period." (letter from RTCA to Jane Garvey, Sept. 3, 1998). In the same letter, the Steering Committee recommended that a plan be prepared that "includes simulations and test flights at the FAA William J. Hughes Technical Center and other available laboratories to address requisite human factors issues as originally scheduled." The purpose of this document is to present a consensus based plan to mitigate risks associated with CPDLC human factors elements, and enable a successful operational deployment of CPDLC.

1.1 Background: Current En Route CPDLC Implementation Path

The FAA's goal is to provide a full range of ATN-based CPDLC services in en route airspace by 2005. The currently accepted path provides for a phased-implementation of ATN-compatible CPDLC services, beginning with a key site evaluation of a limited set of services and maturing to a national deployment of a full set of services. To mitigate implementation risks, the FAA will develop CPDLC in four phases, with additional messages and capabilities supported for each Build: CPDLC Build 1, CPDLC Build 1A, CPDLC Build 2, and CPDLC Build 3. It is assumed that transition to phases beyond Builds 1 and 1A will be contingent upon the success and "lessons learned" from these Builds. That is, the evolutionary CPDLC path assumes that issues and improvements identified from initial operational use are fed into the ongoing development activities to facilitate deployment of increasingly mature baseline capabilities with each increment of new CPDLC capability.

CPDLC Build 1

CPDLC Build 1 is the first step in the development of the en route CPDLC program. CPDLC Build 1 will leverage the evolving capabilities of the existing National Airspace System (NAS) infrastructure, air/ground communication service providers, and avionics.

The CPDLC Build 1 messages will be exchanged with data link-equipped aircraft using ARINC's Very high frequency Digital Link (VDL) Mode 2 air/ground communications subnetwork. The message set has been defined to perform the following services:

1. Transfer of Communication (TOC)
2. Initial Contact (IC)
3. Altimeter Setting (AS)
4. An informational predefined message capability, which allows an air traffic supervisor to compose and assign messages to specified controller positions.

CPDLC Build 1 capabilities will be assessed at WJHTC in December 2000, with emphasis on evaluating human factors. It is anticipated that American Airlines will be the launch airline and that CPDLC Build 1 will become operational at the Miami Center in June 2002.

CPDLC Build 1A

CPDLC Build 1A will enhance ATS communications by increasing the message set to accommodate assignment of speeds, headings, and altitudes as well as a route clearance function. A capability to handle pilot-initiated altitude requests will also be implemented. CPDLC Build 1A will continue to use the VDL Mode 2 air/ground communication subnetwork. CPDLC Build 1A is planned for a key site implementation in June 2003 with national deployment commencing thereafter.

CPDLC Build 2

CPDLC Build 2 will expand upon CPDLC Build 1A in terms of services and messages provided. CPDLC Build 2 will continue to use the VDL Mode 2 air/ground communication subnetwork, but will evolve the subset of the ATN CPDLC messages to support CPDLC operations for several years. These messages will be coordinated across adjoining ICAO regions and will accommodate multi-part uplinks (e.g., crossings with time, speed, and altitude restrictions) and report instructions. The downlink capability for pilots to request clearances and respond to requests via CPDLC will be greatly enhanced.

CPDLC Build 2 will be fielded at a key site in December 2004 with national deployment commencing thereafter.

CPDLC Build 3

The deployment of CPDLC Build 3 is the last of the currently planned phases in the FAA's Aeronautical Data Link program. Details of the increased capabilities remain to be determined, but are likely to include additional messages from the ICAO Annex 10 CPDLC message set. CPDLC Build 3 is expected to use NEXCOM, a more robust air/ground communications subnetwork based upon VDL Mode 3 technology.

1.2 Human Factors Related Elements in CPDLC

This section describes five major elements for CPDLC, each of which has human factors components and requires guidance material and data to enable effective CPDLC system performance. The elements are intended to support human users of the CPDLC system who make a contribution to its performance. The human users include ATSSs (controllers, supervisors, and system maintainers) and flight crew members.

CPDLC Message Data and User Information Requirements

A fundamental requirement for the CPDLC system is that the human users who are communicating with each other understand the meaning of all messages presented by the system. These include controller-pilot messages containing air traffic service or free text information and system messages indicating system/transaction status, failure modes, and error notifications. Moreover, it is important that both the controller and the pilot have a common understanding of the meaning of all controller-pilot messages and the appropriate operational responses.

Human Computer Interface (HCI)

From the standpoint of CPDLC system performance, an effective HCI for the controller and for the pilot is critical. HCI considerations pervade all aspects of system design. HCI entails more than effective display or keyboard design. It also includes the structure and order of the user's tasks, the sources of data, what the user must do with data, where the data go, and the relationship among tasks that different users must be performing.

Furthermore, the CPDLC HCI will be integrated with the existing pilot and controller workstation capabilities. Human factors in flight deck and controller console integration include consideration of the layout and capabilities of the target aircraft and controller position and the interaction of CPDLC with other aircraft and ground subsystems.

For CPDLC, controller and pilot HCI's must be evaluated separately and as a joint system to uncover human factors concerns. In addition, controller and pilot HCI's must be evaluated to ensure that they can support team operations between sector controllers and flight crew members. Finally, the ground CPDLC system requires an evaluation of an HCI for an air traffic supervisor and for an airway facilities system maintainer.

Procedures

This element concerns the controller-pilot operational communication procedures, controller team procedures, and flight crew procedures associated with the CPDLC system. Human factors considerations in this area relate to assuring that multiple users on the ground and in the air have a common understanding of the steps in conducting the air-ground dialogue, the cues that indicate when each step is completed, the ordering and timing of those steps, and their responsibilities in carrying out these procedures. Controller-pilot operational communication procedures define the process, sequence, and priority of the non-automated message sending and receiving tasks. These tasks are performed to assure that the message intent has been accurately communicated to the intended recipient. Operational communication procedures also address tasks related to failure modes and use of alternative means of communication. Flight crew and controller team procedures define additional actions, such as oral and manual coordination, between controllers and between pilots that are designed to ensure shared awareness of the message information and status of the transaction.

Qualification

The qualification element addresses the content of the materials and program of activities developed to prepare the system users to operate the CPDLC system and maintain their performance. CPDLC will require development of training and qualification activities for controllers, pilots, supervisors, and maintenance personnel. The effectiveness of the training must be evaluated with respect to qualification criteria, so that appropriate knowledge, skills, and abilities are assured. The controller and pilot packages must be assessed to ensure that they present consistent information and convey an understanding of both users' roles and task environments. This activity is being worked, in part, by the Communications Surveillance Operational Implementation Team (C/SOIT) Training Working Group.

Operational Performance

This element addresses the integration of ground and air system elements in the context of each user's operating environment to produce an effective overall system performance. It addresses the influence of factors such as information and procedural consistency and compatibility, system response time, operator errors, and the effects of varying and degraded system performance characteristics. Such factors have been shown to affect the human user's ability and willingness to use the system.

1.3 Approach

A human factors working group was formed to develop a human factors plan for CPDLC. This group developed a data link human factors roadmap based on the following approach:

1. Review previous and currently planned work and compare it with human factors elements on current CPDLC implementation path.
2. Identify gaps and discrepancies for mitigating current human factors risks.
3. Recommend modifications to planned activities and propose additional activities.
4. Review CPDLC development milestones and propose a timeline for recommended CPDLC human factors activities.
5. Apply recommendations from recent FAA Standard Terminal Automation Replacement System (STARS) Human Factors Process Group to define roles and responsibilities for oversight, coordination, and technical conduct of human factors. activities.
6. Establish consensus on recommended roadmap.
7. Obtain commitment to the plan milestones and deliverables from FAA and industry participants.

1.4 Scope

The scope of this roadmap considers all Builds of CPDLC. It focuses on the initial CPDLC services and users, integrating human factors into the process at the earliest possible phase in the approved path. This roadmap addresses human factors issues of (1) ground and airborne HCI design and usability, (2) pilot and ATSS operations, procedures and training, and (3) ATSS/pilot/system interaction.

The activities identified in this roadmap are required to ensure that human factors issues are adequately addressed in the operational CPDLC system. The activities include human-centered test and evaluation activities, occurring as part of CPDLC test and evaluation. In addition, the activities also lead up to an ATSS/pilot/system integration demonstration. This demonstration is intended to provide early evidence that human factors risks associated with the initial CPDLC services have been addressed prior to operational deployment and is therefore scheduled to occur in the FFP1 time frame, beginning in December 2000.

This roadmap presents a timeline of human factors activities that parallels the CPDLC system development schedule and permits feedback of human factors results in advance of cutoff dates for key milestones. The roadmap describes activities at a high level and does not provide detailed test plans or procedures. However, it identifies organizational roles and responsibilities for detailed planning and execution of the activities.

1.5 Organization of this Report

The remainder of this report contains five sections, based on the approach specified above. Section 2 presents a review and assessment of previous work. Section 3 reviews and assesses ongoing and planned activities and identifies gaps in those activities. Section 4 recommends a set and sequence of activities to coordinate, redirect, and fill the gaps in the planned activities and presents a timeline for executing the activities. Section 5 identifies roles and responsibilities for execution of the roadmap. Section 6 discusses human factors activities required for future communication services.

Following these sections, are three appendices that contain supplemental material: Appendix A contains a detailed review of previous simulation research on data link and a bibliography, Appendix B contains the membership roster of the CPDLC human factors working group, and Appendix C contains the CPDLC integrated schedule.

Section 2

Assessment of Previous Work

As part of our approach, the data link human factors group reviewed the previous work and compared it with human factors elements on the current implementation path. During this review the group identified over 50 reports, spanning a twenty year period, including recent reports on FANS and PETAL operational trials. Appendix A contains a detailed review of much of this research and a bibliography of the original reports. The results of these early works were synthesized and captured in a core set of FAA-industry data link human factors standards and guidance documents (SAE ARP 4791A and RTCA DO-238).

In reviewing the guidance materials with some of the original researchers and co-chairs of the RTCA and SAE data link human factors working groups, it became clear that some of the fundamental assumptions that served as the basis for developing the original materials have changed. In addition, there have been lessons learned from in-service use of CPDLC. Therefore, the requirements and guidance documents for both the ground and airborne side need review, validation, and modification. This is a key step in the roadmap, which must include lessons learned from the operational experience from FANS 1 use in the South Pacific, and from the PETAL I trials. This section assesses the status of the previous ground and airborne side research in terms of its relevance to the current CPDLC plan. It also provides a synopsis of the recent operational trials.

2.1 Simulation Research

2.1.1 Air Traffic Side

Data link human factors work related to ground side air traffic services was initiated by an iterative series of prototyping and simulation studies to develop and progressively refine the design of the HCI and the communications equipment and procedures. This work has been a collaborative effort by researchers and system developers at MITRE, the William J. Hughes Technical Center (WJHTC) and the Air Traffic Data Link Validation Team (ATDLVT), a team of experienced en route and terminal controllers representing a range of field facilities.

Since the work of the ATDLVT began, there have been significant changes in the implementation path envisioned for data link. As a result of these changes, a number of new human factors risks have arisen. These include HCI design issues associated with the transition from the Plan View Display (PVD) workstation that was used in the previous studies to the en route Display System Replacement (DSR) workstation that will be used in the current CPDLC implementation. In addition, there are operational system performance issues associated with the transition from the Mode-S based communication system that was simulated in the previous research and the ATN/VDL-2 based system that will be used in the current CPDLC implementation.

2.1.2 Flight Deck Side

On the airborne/flight deck side, there is a body of simulation studies conducted primarily by NASA, the WJHTC, and EUROCONTROL. This work has served as a basis for the existing human factors requirements on flight deck HCI and procedures (SAE ARP 4791 and RTCA DO-238). Although this early work provided a useful knowledge base for human factors guidelines, it was not closely coordinated toward a specific operational CPDLC capability.

It should be noted that currently envisioned data link systems are drastically different from what was anticipated ten years ago when much of the data link research was initiated. Significant developments and recent CPDLC path changes introduce a host of new human factors issues for pilots, which include the alerting mechanism that will be acceptable for pilots, controls and displays for data link messages, and operations and training considerations.

2.2 Operational Trials - ODL, FANS, and PETAL

CPDLC has been in operational use since 1995 at one Oakland Center sector that is equipped with an oceanic data link (ODL) prototype and in other non-US ATS facilities in the South Pacific. A number of airlines have equipped with Future Air Navigation Systems (FANS) 1 avionics to participate in these trials (Horton & Joseph, 1998; FANS Interoperability Team, 1998). The experience gained from these trials includes the identification of several human factors issues as well as technical and programmatic issues. Chief among these were issues associated with lapses in end-to-end performance without controller knowledge and the inadequacy of the procedural solutions developed to compensate for these lapses. Air and ground HCI issues were also identified. On the air side, a primary issue has been the ability of the crew to accurately interpret air traffic clearance messages. For ground systems, problems have been noted with the controller's ability to accurately and easily compose a message for uplink and the unanticipated use of free text for composing clearance messages. In addition, the operational trials have further highlighted the importance of adequate training and regular practice to sustain reliable human performance. At a programmatic level, the ODL-FANS/1 experience identified two key lessons. First, it is important to begin the program with a single agreed upon operational concept from which system requirements and procedures can be derived. Second, it is important to establish an integrated feedback mechanism to ensure that human factors solutions are identified and resolved in a timely manner.

A preliminary EUROCONTROL test of air/ground data link (PETAL) project began in 1994 with the first operational trials, PETAL I, conducted between May 1995 and April 1996

(Barnetche, et al., 1996). In the PETAL I program, Eurocontrol evaluated CPDLC in busy en route airspace in Europe with Airbus Industrie aircraft. This trial was designed for the express purpose of obtaining data on operational benefits, requirements, human factors, and procedural issues associated with using data link in the en route environment. However, PETAL I trials completed to date are of limited use, since these were conducted in a research test environment using only one data link equipped aircraft active in one sector at a time. The results of the PETAL I trials include a set of HCI design and procedural recommendations and requirements. These are analogous to the requirements described in the SAE and RTCA human factors requirements documents. The results also point out priorities for additional human factors research. These include: definition of flight crew and controller team procedures, design of a flight deck alerting mechanism for data link, use of logical acknowledgments to indicate reception of a data link message by the end systems, and design of pilot and controller training programs.

A follow-on series of trials, Petal II, has been underway since mid-1996. Petal II will involve multiple aircraft using datalink communications during routine air traffic control (ATC) operations. The trials focus on operational aspects of air-ground data link for air traffic service communications. Several commercial aircraft operators are participating and ATN-quipped aircraft will be involved. Therefore, results from the Petal II experience will be more directly relevant to CPDLC than the Petal I results and should help validate and expand the base of data link human factors requirements and guidance information.

Section 3

Assessment of Ongoing and Planned CPDLC Human Factors Activities

This section contains an assessment of all data link human factors activities currently funded by the FAA. The four organizations that receive FAA funding for these activities are: the WJHTC, the NASA Ames Research Center (ARC), the MITRE Corporation Center for Advanced Aviation System Development (CAASD), and the FAA Civil Aeromedical Institute (CAMI).

It should be noted that at the time this report was prepared, the group was unable to obtain any detailed information on what, if any, industry-sponsored human factors data link activities are planned or underway. Thus, the remainder of this section will focus on an assessment of each of the four FAA funded research organizations, followed by an overall assessment, which identifies gaps across programs and general recommendations.

3.1 WJHTC Activities

3.1.1 Controller/Ground System Activities

The Data Link Branch of the WJHTC has been the focal point for ATSS/ground-side development and simulation testing of CPDLC since 1987. The program has developed CPDLC service and controller HCI requirements for existing and future systems. These include designs for the en route Host/PVD and the terminal ARTS IIIA and ARTS IIIE systems. General CPDLC HCI design principles have been synthesized from multiple controller simulation studies. These principles are being applied to design the DSR controller HCI in the CPDLC testing facility. In addition, research has examined controller use of CPDLC in mixed communications environments, CPDLC effects on controller workload and performance, the impact of extended transaction delays, and CPDLC use by individual controllers and control teams. The WJHTC also performed the Data Link benefits studies, which involved high fidelity testing of domestic CPDLC, and included real-time simulations with both controllers and piloted flight simulators.

Planned human factors research will focus on the refinement and operational testing of CPDLC procedures. This work will examine controller-pilot procedures, individual controller procedures, and controller team procedures, to ensure their effectiveness and robustness in a range of operational environments. Additional HCI research will be conducted to exploit the advanced display and input capabilities of the DSR platform as they become available in future system Builds.

Planned Operational Test Activities

- DSR/HCI: A data link DSR keyboard study was conducted to identify acceptable DSR key locations for composing messages and for selecting CPDLC I settings (Darby and Shingledecker, 1998). This activity is intended to evaluate all CPDLC display/control functions.
- Suitability Tests: This activity entails a CPDLC 1 documentation, training, and maintenance evaluation.
- Effectiveness Tests: Tests to determine whether the use of CPDLC 1 by controllers adversely impacts ATC operations or the quality of air-ground communications, and to determine whether the CPDLC 1 controller HCI and training effectively support AT operations.

Assessment of and Recommendations for Re-Directions of WJHTC Controller/Ground System Activities

The currently available plan for WJHTC activities is directed toward an ACARS implementation of the four CPDLC Build 1 services (FAA, 1998b). Because the ACARS implementation has been eliminated, the planned air traffic services effectiveness tests should be tailored to focus on those aspects of CPDLC 1 ACARS which will be identical to the CPDLC 1 ATN implementation.

A reduced ACARS test can still be valuable from a ground perspective, but it should involve a small number of controllers who are already familiar with basic DSR functionality. With the scaling back of the ACARS test, emphasis should be shifted to Build 1/ATN CPDLC human factors elements. Because the functionality differs between the ACARS and the VDL-2 implementations, the full HCI, training package assessment, controller team interaction, procedures assessment, and operational performance testing should be accomplished using Build 1/ATN functions.

Additional ground system human factors activities should be planned to address the supervisor and system maintainer HCI, training, procedures and performance assessment. It also is critical that air traffic procedures for non-normal situations are developed and tested. Examining issues and recommending procedures for dealing with auto-uplinked altimeter settings is another area that must be examined both on the ground and in the air.

Finally, efforts should be stepped up to develop the human factors activities in an operational test plan for ATN-based CPDLC Build 1 and the evaluation plans for addressing human factors issues associated with CPDLC Builds 1A and 2. This plan should include development of a CPDLC controller HCI checklist for evaluating the DSR implementation.

3.1.2 Pilot/Flight Deck System Activities

Since 1989, the WJHTC has provided an integrated simulation and flight test capability for the analysis of interactions between new and existing aircraft systems. The WJHTC has supported the development of airborne CPDLC applications and guidance documents. Researchers have conducted literature reviews and analyses, Aviation Safety Reporting System (ASRS) reviews, part task and full mission simulations of Data Link in terminal, enroute, and oceanic airspace. A central theme in each of these efforts is the effect of CPDLC on the flight crews from the points of view of workload, errors, vigilance, situation awareness, and system performance.

Planned Operational Test Activities

- <u>Avionics HCI ACARS Acceptability Assessment:</u> Activity is intended to evaluate flight crew training and operational procedures for the use of the cockpit ACARS display device. Screen presentation formats, data entry options, and installation options will be examined.
- <u>Effectiveness Tests:</u> Tests to determine whether the use of CPDLC I by flight crews adversely impacts their normal flight routine or the quality of air-ground communications. Additionally, this test will determine whether the CPDLC I flight deck HCI, training, and crew coordination procedures effectively support AT operations.

Assessment of and Recommendations for Re-Directions of WJHTC Pilot/Air Side Activities

The Flight Deck HCI assessment should reflect the AAL design and installation plan. This installation will be designed to be compatible with the Petal II extension to ATN as well as CPDLC. The Petal II functions exceed those in CPDLC Build 1 and should enable early assessment of much of the CPDLC HCI for Build 1A and 2 functions. Results of these assessments should be incorporated in human factors guidance materials.

Controller/pilot/system testing must be defined to address the requirement for system feedback and end-to-end message assurance. Results of Petal I operational trials have recommended a “logical acknowledgment” (LACK) for data link transactions. However, these trials were limited and did not include any ATN equipped aircraft. Requirements for system feedback and message assurance must be evaluated for an ATN-based CPDLC system.

Finally, the scope of the flight deck effectiveness testing should be redefined to determine whether CPDLC is effectively integrated with all flight deck functions including but not limited to AT operations.

3.2 NASA ARC Activities

The NASA ARC data link human factors work has involved examining human performance issues for commercial flight crews. NASA has run several simulation studies which represent data link communications and voice communications (for ATC clearance information) in a realistic environment. These studies compared the human performance data for these two modalities, with special emphasis upon crew procedures and communications.

Over the past several years, this research has revealed some important differences in crew performance when handling an ATC clearance via textual data link as compared to voice. The data suggest that the average time required for a crew to complete a data link message is longer than to complete a voice message (usually about twice as long). Additionally, flight crews are more likely to be distracted while handling a data link message compared to voice message, and crews using data link also take longer to resume the communications task once they are distracted. NASA researchers have also examined different formats for flight deck data link communications. When comparing textual data link to graphical data link, they found that each of the formats had particular strengths, depending upon the content of the message.

In addition, NASA has conducted joint research with Boeing to examine issues associated with alternative data link installations and with MIT to assess the impact of data link on party line information and situation awareness. Most recently, NASA has been investigating human factors in FANS 1 and ODL.

Assessment of and Recommendations for Re-Directions of NASA Activities

Currently, NASA Ames is the only research organization actively involved in the human factors activities associated with FANS 1 and ODL. Previously, the WJHTC and CAMI have studied human factors aspects of the ODL system (FAA, 1998a). However, the results of the FANS 1/ODL experience have not been integrated into a single compendium of useful and applicable lessons. Thus, it is critical that NASA focus its near term efforts on a compendium of human factors lessons learned from this operational experience to ensure that the CPDLC program appropriately incorporates the lessons learned. This compendium should be structured to be useful to the FAA Certification and Flight Standards specialists, who approve equipment, installations, operations, and procedures, and to the operators and developers who build the air and ground systems. The compendium should provide information that helps system developers and evaluators understand the operational requirements for the system. This can include lessons based on features of the CPDLC procedures or the HCI that caused ATSSs or pilots to respond inappropriately as well as lessons based on features that facilitated appropriate responses.

One major issue identified in the FANS work has been the lack of a mechanism to ensure problems identified are fed back into the system and addressed in an adequate and timely manner. NASA should focus on resolving this issue for CPDLC. Part of this effort should entail working closely with the WJHTC on the flight deck feedback questionnaires (or alternative mechanisms) described in the WJHTC assessment section.

Current CPDLC development plans are based on assumptions of the timely availability of key products related to operational controller-pilot communication procedures and flight crew procedures. NASA should synthesize its research findings and provide appropriate input to the required products (e.g., advisory circulars for equipment, installations, operations, and procedures). Future efforts should also be focused on providing inputs to the products identified in Section 4.

Finally, NASA Ames should work closely with MITRE and the WJHTC flight deck researchers to cross check the design and implementation of future CPDLC flight deck studies and subject/pilot recruitment procedures.

3.3 MITRE CAASD Activities

MITRE has been working data link human factors since 1987 with special emphasis on ATC/flight deck integration issues. MITRE worked with the FAA Air Traffic Data Link Validation Team to identify controller information requirements and develop operational procedures for data link communications. A series of simulation studies was conducted to define and validate operation concepts for initial data link services.

In addition, MITRE conducted two major reviews of the data link simulation research to synthesize reliable findings and identify a uniform set of data link performance metrics. Results of these reviews are documented in Appendix A. These reviews formed the basis for a MITRE led activity to develop human engineering guidance for data link systems (SAE ARP 4791A; RTCA DO-238).

Recently, MITRE staff members have been asked to play a coordination role in human factors, working closely with the new manager of the FAA's Aeronautical Data Link Program (AND-720) to develop a cohesive integrated plan for addressing human factors in CPDLC. Specifically, this has involved efforts to apply the recommendations from the FAA Human Factors Process report on the STARS program to mitigate human factors risks early in the CPDLC program, a key part of this roadmap.

Assessment of and Recommendations for Re-Directions of MITRE CAASD Activities

A major contribution of the MITRE activities has been its focus on developing products that are useful to both the FAA and industry. However, the guidance material (developed by SAE G10 and RTCA) has recently been criticized for being out of date (not applicable to the CPDLC path) and for containing recommendations that are too "fuzzy" and not amendable to testing against objective, measurable criteria.

It is recommended that MITRE focus on addressing these issues and updating the existing human factors requirements in light of the current CPDLC implementation path. These should be folded into the appropriate advisory circulars and other relevant products and requirements should be documented for each CPDLC Build.

Additionally, MITRE should continue to work closely with AND-720 to develop and implement a plan to address human factors in CPDLC. Part of this implementation should include establishing a peer review process that includes appropriate FAA organizations and industry representatives. Finally, MITRE should focus on developing a recommended process for developers of systems (air and ground) to address human factors issues early in the design process. This activity is a more long term goal to provide manufacturers and the FAA with a path for preventing human factors problems in all systems, not just CPDLC.

3.4 CAMI Activities

CAMI has been involved in research and development related to both the air and the ground systems for data link. For the ground systems, a simulated PC-based prototype of controller-to-pilot data link communications was developed for use on CAMI's TRACON simulator. The CPDLC software made use of existing ARTSIIIA and PVD features. Although different in some respects from the current software designs being evaluated for CPDLC Builds 1/1A, the fundamental concept of sending routine air traffic control information and instructions by a data link was explored in several simulation studies. Areas of study included the impacts of traffic density (light vs. heavy), modality (voice-only vs. voice plus data link), and workload. On the airborne side, CAMI has also conducted research on the impact of increasing automation in the General Aviation and commuter flight environments.

Future research activities may include a prototyping study to examine data link design alternatives for the display of uplink messages and downlink pilot responses. Additionally, work may investigate message sequence, format, display integration, confirmation actions, and authority sharing issues, among others, for general aviation applications.

Assessment of and Recommendations for Re-Directions of CAMI Activities

With respect to the near term CPDLC human factors needs, two strengths of the CAMI program have been its general aviation research program and its proximity and ability to coordinate with the FAA's Air Traffic Service Specialists training facility (co-located with CAMI at the Mike Monroney Aeronautical Center in Oklahoma City). Over time, as general aviation aircraft plan to equip with CPDLC, CAMI's focus on the GA community can be leveraged facilitate validation and analysis of flight deck human factors requirements.

At this point, it is not clear whether CAMI research in FY99 will have a data link component. If CAMI does receive funding for data link research, it is recommended that in the near term, future research activities at CAMI focus on the Air Traffic Service side.

Specifically, work is recommended in the area of training and procedures for non-normal situations.

3.5 Overall Assessment

Looking across organizations, programs, and projects it is clear that several deficiencies exist and re-directions are appropriate. Five cross cutting recommendations were identified to address the deficiencies.

1. Activities in all four of the organizations need to be re-aligned to focus on the current CPDLC path, not on ACARS testing. Specifically, activities need to be directed toward the initial CPDLC operational capability and generate products that support future enhancements of the capability.
2. The organizational structure of the FAA, and its associated funding mechanism, makes coordination, collaboration, and identification of gaps and redundancies difficult, if not impossible. The four organizations that conduct data link human factors activities (described above) are funded by three different sponsors, representing two different organizations within the FAA. A new mechanism to coordinate CPDLC human factors activities is needed. These sponsors do not coordinate systematically on plans for data link activities, exchange research proposals, nor do they have a mechanism for identifying deficiencies and redundancies. The coordination required to develop this roadmap is a step in the right direction, but is clearly is not enough. In the recommendations section, this working group recommends a technical review and exchange process to facilitate coordination and communication between the sponsors, as well as the researchers.
3. The current plans reflect very little coordination with industry. Thus, many of the efforts have been focused on examining scenarios and designs that are not likely to be implemented. Increased coordination with industry is needed to ensure the activities are timely and of maximum effectiveness.
4. A necessary tool for promoting a coordinated human factors program among many government and industry participants is a shared CPDLC operational concept. All government and industry CPDLC human factors work should be guided by a single, agreed upon CPDLC operational concept. Procedures and human factors requirements should also be based on the operational concept. Presently, an FAA/Industry Concept of Operations for Aeronautical Data Link (FAA, 1998c) is under development by the government industry team overseeing CPDLC (i.e., John Kern group). This draft concept should be reviewed and adopted as high-level guidance by the organizations working on CPDLC human factors.
5. At present, there is no mechanism in place to monitor human factors issues and lessons learned throughout development and deployment cycle and feed back results

to ongoing development activities (e.g., follow on applicants). A process and structure should be established to monitor and track CPDLC human factors status.

Additionally, the review of the on-going and planned activities revealed the following deficiencies and gaps:

1. Inadequate human factors standards in FAA guidance material (AC's, etc.).
2. Industry standards and guidance material (SAE ARP 4791A; RTCA DO-238) need to be updated, made more rigorous, and made appropriate for inclusion in AC's.
3. Not enough emphasis on the FANS, ODL human factors lessons learned.
4. Many activities are not directly tied to FAA products (e.g., Advisory Circulars 20-DC and 120-COM, training bulletins, FAA Order 7110.xx, the AIM).
5. Not enough coordination between organizations conducting similar research (e.g., NASA and the WJHTC Air Side, CAMI and the WJHTC ground side researchers).
6. Organizations are not taking advantage of their internal organizational resources:
    - CAMI should work more closely with ATS training program.
    - WJHTC air and ground side researchers should develop an integrated plan (right now the plan appears to be two separate pieces: air + ground).
    - WJHTC data link air and ground researchers should work with other WJHTC organizations that have data link human factors expertise (e.g., the data link branch (ACT-350) should consider tasking and funding collaborative work with the researchers in the human factors lab, ACT-530).
7. Testing has neglected:
    - Non-normal scenarios
    - Controller team procedures
    - Pilot procedures for receiving conflicting altimeter settings from the auto-uplinked data link system vs. voice messages from the controller
    - Pilot acceptance and nuisance issues associated with auto-uplinked altimeter settings (predicted to be much more frequent than traditionally given with voice-based systems)
    - Pilot issues associated with Logical Acknowledgment (LACK). A LACK is used in Europe, but is not planned for use in the USA. Do we need them in the USA? What are the implications for pilots flying in and out of environments where a

LACK is used and other times when it is not? Will pilot confusion discourage use of the system?

- Pilot issues associated with the fact that planes will be flying in and out of different sectors/facilities where data link is not used universally. Will confusion discourage use of the system?

8. Test participant (pilot and air traffic specialists) selection criteria have been criticized as inappropriate and not representative (note: criticism made across organizations).
9. No plan to provide human factors input on areas that need special attention in training materials.
10. No planned evaluation of training material for pilots, is it adequate? Should the FAA provide specific guidance or require additional pilot training for data link?
11. Not enough emphasis on CPDLC integration with the full set of flight crew CNS functions.
12. Not enough emphasis on Air Traffic Specialist supervisor and maintenance roles and tasks.
13. Not enough emphasis on recommendations for how to handle "free text" options on the ground, between centers. Issue needs to be examined from the air and the ground perspective.

3.6 Summary Recommendations Across Programs and Organizations

1. Activities at all organizations (WJHTC, NASA, MITRE, and CAMI) - air and ground work should be re-directed to focus on ATN-based CPDLC services (i.e., DSR ground and AAL airborne avionics instead of ACARS).
2. All activities funded by the FAA should be more directly focused on providing human factors guidance and minimum requirements input to FAA products (Advisory Circulars 20-DC and 120-COM, training bulletins, FAA Order 7110.xx, and the AIM).
3. All FAA CPDLC human factors activities should be coordinated both internally within the FAA (across sponsoring organizations) and externally with industry.
    - Programs and activities should go through a technical/peer review process.
    - Program content should be traceable to the CPDLC operational concept.
4. Prior to FAA funding, all organizations should submit clear proposals indicating which tasks in this roadmap they are supporting and how. Proposals should include

detailed task descriptions, milestones, interim and final product deliverables as well as the project sponsor (which FAA organization has a need for the products).

5. Initial avionics work should focus on AAL, since that is the first applicant, but the work output should be general enough to be useful to other applicants. The focus should shift from AAL to other applicants as they step forward for certification and/or operational approval.

Section 4

Recommended Human Factors Roadmap

Based on the assessments and deficiencies identified in the previous section, a roadmap of recommended activities was developed. The essence of the CPDLC human factors roadmap is a set of activities and a timeline to effectively integrate human factors into the currently planned CPDLC path. Five major activities were identified.

1. Review and update human factors requirements and guidance
2. Test and evaluate ATSS/ground system HCI
3. Test and evaluate Pilot/flight deck HCI integration
4. Test and evaluate ATSS/Pilot/System integration
5. Demonstrate ATSS/Pilot/System Interaction

The proposed activities generally entail iterative studies using partially and fully functional prototypes and, as available, production system components to progressively refine and validate requirements and guidance. The expected outcome of these activities is a demonstration that human factors issues have been adequately addressed in the operational CPDLC system. A key product resulting from these activities is a current and validated set of FAA human factors requirements and guidance material (for inclusion in the appropriate AC's, notices, orders, AIM, etc.) that addresses design specifications, installation issues, procedures, operations, and training for both pilots and controllers.

4.1 Review and Update Human Factors Requirements and Guidance

This task entails a review of existing human factors requirements and guidance (air, ground, and system) as well as incorporating lessons learned from research and operational implementations. A major part of this task that has not yet been attempted entails a thorough review and synthesis of findings from the PETAL, FANS, and ODL trials. Assuring that these lessons learned are adequately incorporated into the data link guidance material currently published by SAE G10 and RTCA is critical. Another part of this task entails the review of existing data link human factors guidance documents to determine which of the guidance is appropriate for each CPDLC Build. It is equally important to determine which of the "recommended guidance" is more critical and should be considered minimum requirements for systems to be certified or approved. These requirements shall be incorporated into an FAA requirements document. The culmination of this task shall result in an updated draft of requirements that need to be validated during prototype and operational tests, as will be described in the following tasks.

Sub-tasks:

1. Review existing CPDLC human factors requirements, guidance, and lessons learned from FANS and PETAL
2. Develop a human factors CPDLC requirements checklist for air and ground systems
3. Pretest human factors checklists for ground and airborne systems on existing CPDLC implementations, ODL, and FANS 1.

Resulting Products:

1. Compendium of HF lessons learned from FANS and PETAL trials
2. New draft human factors requirements for ground and airborne systems (hardware/software)
3. Recommended requirements and guidance beyond Build 1A
4. Checklist for ground and airborne systems (hardware/software)

4.2 Test and Evaluate ATSS/Ground System HCI

This task entails validating and refining the requirements and guidance for the ground system CPDLC software and its implementation on the DSR hardware and for controller training, operations, and procedures. Three sets of activities are proposed to supplement and replace the activities described in the CPDLC Build 1 ACARS Operational Test Plan (FAA, 1998b). The proposed activities focus on ATN-based CPDLC/Builds 1, 1A, and 2. They should include an HCI design and usability study, evaluation of procedures, and a training assessment. Each type of activity is conducted for controllers, supervisors, and maintenance operators.

The first activity is a system design and usability study. This study would take the checklist resulting from task 1 and compare the requirements against a DSR HCI prototype that has ATN-based CPDLC functions represented. For this study, participating controllers should be familiar with DSR HCI to check for CPDLC design consistency with other workstation conventions. Further usability studies should be conducted to evaluate the supervisor and maintenance HCI's. To the extent that the ACARS-based CPDLC HCI for the supervisor and maintenance operator is identical to the ATN-based CPDLC HCI, that software and hardware may be used as an HCI prototype. Results and recommendations from all of these studies must be fed back into the CPDLC engineering process so that the HCI can be refined prior to formal Operational Test and Evaluation.

Two additional sets of activities are proposed to evaluate the training and procedural guidance developed for controllers, supervisors and maintenance operators. For controllers, a DSR HCI prototype with ATN-based CPDLC functions is needed. R and D controller teams should participate to examine issues of task allocations, team coordination, and R and D Controller access to data link interactive functions and display information. Training materials should be evaluated to ensure that they are effective and appropriate for each category of users. Any HCI design recommendations from these studies must be fed back into the CPDLC engineering process. In addition, training and procedural recommendations are fed back to refine the training package and the FAA Order on data link procedures.

Table 4-1 summarizes the controller/ground system activities. As shown in the table, the results and products of these activities will address four of the five CPDLC human factors elements identified in Section 1. These elements are: 1) messages, 2) HCI, 3) operations and procedures, and 4) training, ensuring that human factors considerations are adequately addressed in the CPDLC program.

4.3 Test and Evaluate Pilot/Flight Deck HCI

This task entails validating and refining the requirements and guidance for the avionics hardware/software, training, operations and procedures. The first step would be to take the checklist, resulting from task 1, and check the requirements against representative avionics. Initially, this would involve testing the requirements against AAL's Collins/Boeing avionics, since AAL is the initial applicant and the avionics configurations are relatively well defined. Subsequent testing of alternative avionics and configurations should be done as additional operators express interest and can provide adequate information. Multiple system and configuration tests will enable a more robust testing of the avionics and installation configurations, as well as an assessments of the applicability of the requirements to different segments of the user community. Additionally, usability studies of prototype representations of the CDPLC ATN compliant systems early on in the design development and testing phase would minimize re-design risks and maximize the potential to catch critical system design issues. It is critical to have representative active line pilots during the iterative usability tests of both the prototypes and the actual systems prior to implementation. Moreover, to the extent possible, initial studies should also include FANS and PETAL experienced pilots to leverage their expertise in the HCI design and CPDLC procedures.

Since training material, operations, and procedures are developed by the airlines, the usefulness of these tests will be heavily contingent on how much the airlines are willing to share the information with the research community for testing and evaluation. At a minimum, operational and procedural tests should be conducted to provide input and minimum requirements for the FAA's advisory circulars and training bulletins on data link.

Table 4-1. ATSS/Ground System Human Factors Activities

Activity	Activity should result in:	Products:
System design and usability study[1]	• Validation of HF user interface requirements and guidance • Recommendations for changes	• CPDLC HCI specification (revisions) for controller and supervisor systems • HF checklist input
DSR checklist analysis [1]	• Check requirements and guidance against DSRs	• Completed checklist evaluations for controller and supervisor systems and input for revisions to requirements/guidance
Ground operations, procedures[1]	• Procedural guidance	• Input to FAA Order 7110.XX • HF checklist input • Recommended supervisor procedures
Training assessment[1 & 2]	• Recommendations for improvements in training materials and procedures	• Training material revisions
Maintenance issues study[3]	• Maintenance HCI, training, operations and procedures recommendations	

Note 1—indicates that this activity requires a DSR HCI prototype with ATN-based CPDLC functions.
Note 2— indicates this activity requires draft training package.
Note 3—indicates this activity requires a prototype maintenance system.

Table 4-2 summarizes the pilot/flight deck side activities. As shown in the table, the results and products of these activities will address four of the five CPDLC human factors elements identified in Section 1. These elements are: 1) messages, 2) HCI, 3) operations and procedures, and 4) training.

4.4 Test and Evaluate ATSS/Pilot/System Integration

This task will take input from tasks 3 and 4 and involves the first end-to-end system-wide evaluation of working prototypes of the system. This will require at least working prototypes, if not actual, representative hardware and software for both the ground and airborne components. The two components will be connected and trials will simulate normal

and
non-normal scenarios. Training, operations, and procedures requirements will be evaluated as well as the adequacy of the systems design for its intended function. Based on lessons learned from FANS, we now realize that it is critical that both the hardware/software components and the people (controllers and pilots) be representative and also connected interactively in real-time to identify the system issues that cannot be addressed in part-task simulations of either the ground or airborne tests in isolation. It is important to identify and correct these issues prior to full implementation and as early in the process as possible in order to avoid expensive re-designs and inefficient training work arounds.

Table 4-2. Pilot/Flight Deck Human Factors Activities

Activity	Activity should result in:	Products:
Flight deck design and usability study[1]	• General validation of HF user interface requirements and guidance • Optimization recommendations for AAL	• AC 20-DC • Avionics Certification checklist • AAL HCI report • Avionics buyers guide • HF process guide for manufacturers
Avionics checklist analysis[1]	• Check requirements and guidance against avionics	• Completed checklist evaluations for each avionics and input for revisions to requirements/guidance
Flight deck installation, operations, and procedures[1 & 2]	• Procedural guidance, recommendations and installation guidance	• AC 120-COM • Installation and operations checklist
Training assessment[1,2, & 3]	• Recommendations for improvements in training materials and procedures	• Pilot training bulletin

Note 1—indicates that this activity requires an ATN-based CPDLC avionics prototype.
Note 2—indicates this activity requires draft training package.
Note 3—indicates this activity requires a representative aircraft or simulator.

Table 4-3 includes both pilot and controller issues. As shown in the table, the results and products of these activities will address all five of the CPDLC human factors elements identified in Section 1. These elements are: 1) messages, 2) HCI, 3) operations and procedures, 4) training, and 5) end-to-end performance.

Table 4-3. ATSS/Pilot/System Integration Activities

Activity	Activity should result in:	Products:
Joint air-ground system design and usability study[1 & 3]	• Validation of HF user interface requirements and guidance • Recommendations for changes • Validation of controller/pilot response times	• CPDLC HCI specification (revisions) • Input to AC 20-DC • Input to the HF process guide • HF checklist input
Controller/pilot operations and procedures[1 & 3]	• Procedural guidance	• Input to FAA Order 7110.XX • Input to AC 120-COM
Training assessment[1, 2, & 3]	• Recommendations for improvements in training materials and procedures	• Training material revisions

Note 1—indicates that this activity requires ATN-based CPDLC prototype systems (ground and air).
Note 2—indicates this activity requires draft training package.
Note 3—indicates this activity requires a representative aircraft or simulator.

4.5 Demonstrate ATSS/Pilot/System Integration

This final task will provide evidence that the two critical overarching risk areas targeted in FFP1, human factors and safety, have been adequately addressed in CPDLC. Solutions to the issues identified in the preceding activities will be validated and training and procedures will be finalized. Controllers and pilots, representing the end users at the first operational site, will participate. Test materials and scenarios that will be used in the certification process will be used in this demonstration. To the extent possible, actual air and ground system components will be used. Objective and subjective data will be collected comparing system performance with and without data link. These results will be compared against the required system performance.

Table 4-4 includes both pilot and controller issues. As shown in the table, the results and products of these activities will address all five of the CPDLC human factors elements identified in Section 1. These elements are: 1) messages, 2) HCI, 3) operations and procedures, 4) training and 5) operational performance identified in Section 1.

Table 4-4. ATSS/Pilot/System Integration Demonstration Activities

Activity	Activity should result in:	Product:
Joint air-ground system design and usability study[1 & 3]	• Validation of HF user interface requirements and guidance • Validation of recommendations for changes • Validation of controller/pilot response times	• Input to AC 20-DC • Input to the HF process guide
Controller/pilot operations and procedures[1 & 3]	• Validation of procedural guidance	• Input to FAA Order 7110.XX • Input to AC 120-COM
Training assessment[1, 2, & 3]	• Validation of recommendations for improvements in training materials and procedures	• Training material

Note 1—indicates that this activity requires a ATN-based CPDLC prototype systems (ground and air).
Note 2—indicates this activity requires draft training package.
Note 3—indicates this activity requires a representative aircraft or simulator.

4.6 Timeline for Execution of Activities

To achieve full integration of human factors in CPDLC development, the context in which the activities are set is as important as the activities themselves. Therefore a major part of this roadmap is the sequence and dependencies among the human factors activities and other CPDLC development activities. Figure 4-1 depicts the proposed human factors activities in the context of CPDLC development milestones.

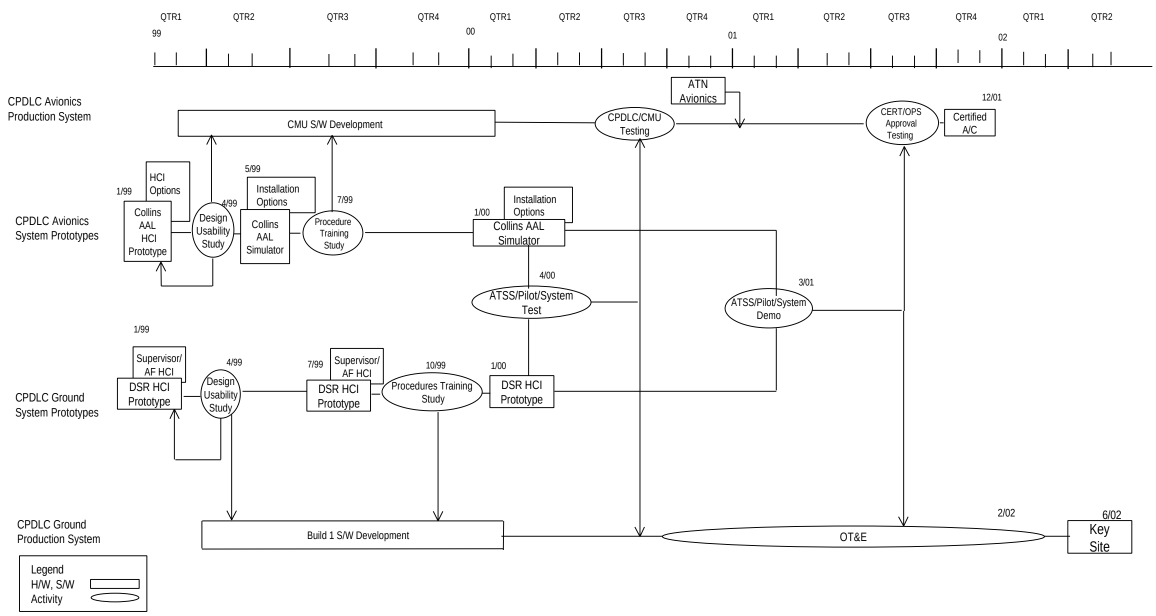

Figure 4-1. Recommended Human Factors Activities in Context of CPDLC Development Schedule

The CPDLC human factors activities will be accomplished over the next few years. The work required in the first two years, including the development of this plan, is presented in the Gantt chart in Figure 4-2.

To affect the ongoing avionics and ground system development, the human factors activities should begin in early 1999. Several contingencies exist in the timeline. For example, an early prototype of the planned American Airlines' HCIs will be required for a flight deck HCI study to evaluate CPDLC and general HCI requirements and identify any needed refinements. A controller HCI study can leverage the ATN-based CPDLC DSR research prototype that will be available at the WJHTC in this timeframe to assess the usability of the controller HCI.

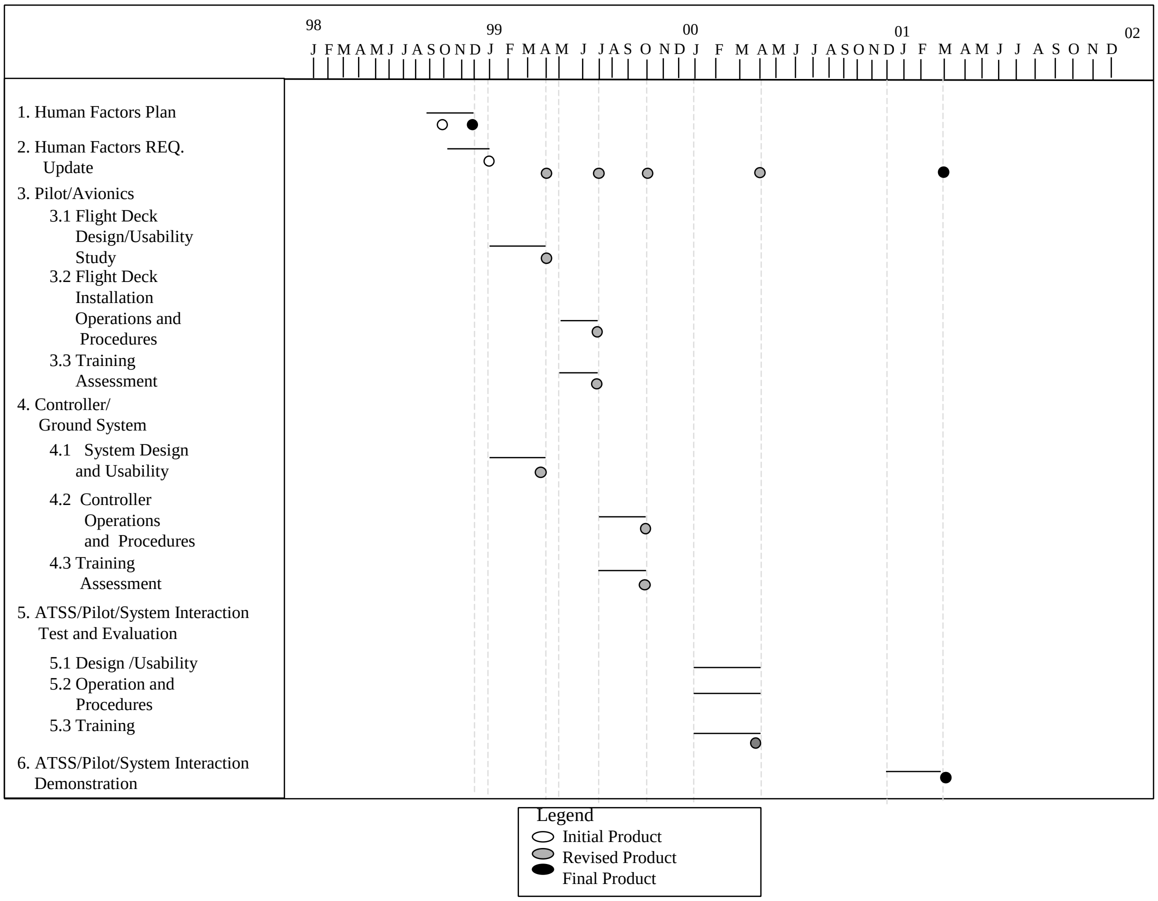

Figure 4-2. Overview of Work Plan for First Two Years of CPDLC Human Factors Activities

Evaluations planned in the late summer and early fall of 1999, require the use of simulators that represent the air and ground CPDLC HCI's integrated into their respective workstations. These studies will assess the effectiveness of the HCI in the context of the proposed message handling tasks and procedures. They will also provide an opportunity to test and refine training materials for CPDLC.

In early 2000, the necessary simulation environment includes air and ground simulators that are linked for an ATSS/pilot/system interaction study to evaluate CPDLC human factors elements in a full operational context. Important considerations in this study are operational communication procedures, end-to-end performance, and failure modes.

Additional cycles of human factors activities are shown behind the flight deck and ground system HCI, procedures and training and ATSS/pilot/system interaction test beginning in mid-2000. For the flight deck, they represent activities to validate alternative implementations proposed by this or other applicants. On the ground side they represent activities to validate requirements, roles, and procedures for other CPDLC users, including the supervisors and maintenance personnel.

Starting in December of 2000, an ATSS/pilot/system interaction demonstration is planned. The study will include as many production system components as possible and will simulate the performance of any components that are not available. Validation of human factors aspects of production system components that are not available in time for this demonstration will be highlighted for further assessment as part of the CPDLC acceptability test component of the Operational Test activity scheduled for late 2001.

This roadmap is an initial CPDLC integrated human factors plan. It is expected to be refined over time. Although the working group recognized that there may be alternative routes to accomplish the integration of human factors into CPDLC, there are two aspects of the roadmap that must be preserved. First, all of the CPDLC human factors elements represented in the prsoposed activities must be evaluated. Second, the results of the activities must be available to support operational test and evaluation of the ground system for Initial Operating Capability and aircraft certification and operational approval.

Section 5

Roles and Responsibilities

The oversight and coordination of CPDLC human factors activities is key to the success of the recommended plan. A recent assessment of human factors in the FAA Acquisition Management System and the Integrated Product Development System (STARS Human Factors Process Group Report, 1998) formulated five major recommendations to maximize the effectiveness of human factors activities. Applied to the CPDLC effort, these would include the following:

1. Establish a structure and process to coordinate CPDLC human factors resources.
2. Clarify roles and responsibilities for human factors activities in all phases of the development cycle.
3. Establish technical liaison positions within NATCA, PASS, and pilot organizations (ALPA, IFALPA, APA) to provide union involvement at appropriate points in the development cycle.
4. Establish mechanism to allocate and manage human factors activities.
5. Establish a mechanism and implementation plan to ensure that human factors recommendations are acted on in a timely manner.

<u>In response to STARS report recommendation 1: *Establish a structure and process to coordinate the CPDLC human factors resources*</u>

It is proposed that a CPDLC human factors lead role be established with responsibility and accountability to work with a government/industry team overseeing development of CPDLC (i.e., John Kern group). The human factors lead will report on the status of human factors activities and present issues that cannot be resolved on technical grounds or that exceed the empowerment of the human factors working group.

A core-working group composed of human factors technical experts and technical liaisons will support the human factors lead. This group will monitor implementation of the plan and technical conduct of the human factors activities, including the process for acquiring users to serve as subject matter experts in human factors activities. In addition, this group will review emerging issues that cannot be resolved within the planned resource and schedule constraints and make recommendations for solution strategies. Periodically, the working group will also review the CPDLC human factors guidance material and ensure that the material is kept current.

In response to STARS report recommendation 2: *Clarify roles and responsibilities for human factors activities in all phases of the development cycle*

In Section 3 (Assessment and Recommendations for Re-Directions) specific tasks and activities were proposed for the government organizations involved in CPDLC human factors. One of the strengths of the approach recommended is that each product (identified in Tables 4-1 through 4-4) is fed by a series of iterative tests that are integrated across programs. As discussed in Section 3, the roadmap proposes a series of checks and balances where each organization is paired with a second organization that works on related projects. The primary or focal point organization for a given activity is responsible for that activity and also for coordinating with the paired, secondary organization to review and provide input into the activity, process, and/or products. These groups are paired to facilitate coordination on related activities. However, each organization will have its own focus areas. Table 5-1 summarizes the focus areas recommended for each government organization.

Active participation of industry organizations is also required to implement this plan. Table 5-2 summarizes the focus activities recommended for each industry organization.

In addition to conducting the technical activities in each focus area the responsible organization should also develop material that directly feeds the related products discussed in Section 4, Roadmap of Activities, tables of activities and products. Table 5-3 identifies the key FAA products and the associated FAA organization responsible for ensuring that the research activities adequately contribute to the associated products.

Table 5-1. Government Roles and Responsibilities

Organization	Primary Focus Areas
WJHTC – Flight Deck	• Human Factors checklist • American Airlines assessment • Training
WJHTC – Ground	• DSR assessment • OPS & procedures • End-to-end coordination • Controller training
NATCA – Ground	• Test participants selection criteria
NASA – Flight Deck	• FANS, ODL, PETAL lessons learned • AC inputs (AFS & AIR AC's)
MITRE – Coordination	• End-to-end test and evaluation plan • AC inputs • Recommended Human Factors process for manufacturers

Table 5-2. Industry Roles and Responsibilities

Organization	Primary Focus Areas
American Airlines	• Provide Flight Deck Simulator • Operational requirements review • Test subjects
Air Carriers	• Operational requirements review • Test subjects
Air/Ground Subnetwork Service Provider	• Subnetwork for End-to-End Demonstration • Assistance with Subnetwork Simulation
Avionics Manufacturers	• Prototype Hardware for Human Computer Interface Evaluations
Pilot Unions	• Operational review; test subjects
CPDLC Software Developer	• Preliminary Human Computer Interface Designs for Early Evaluation

Table 5-3. Responsibilities for Human Factors Input into FAA Products

Product	Responsible FAA Organizations	Primary Responsible Organization
Compendium of HF lessons learned from FANS and PETAL trials (air and ground)	AFS-400 & AIR-130	NASA
FANS lessons learned input to AC 20-DC	AIR-130	NASA
FANS lessons learned input to AC 120-COM	AFS-400	NASA
Updating current info in SAE and RTCA documents for input into AC 20-DC	AIR-130	MITRE
Updating current info in SAE and RTCA documents for input into AC 120-COM	AFS-400	MITRE
Checklist for ground and airborne systems (hardware/software)	AIR-130	WJHTC - Flight Deck
FAA Order 7110.xx	ARN-100	WJHTC - Ground
Modifications to CPDLC specification	ARR-100 & AND-1001	WJHTC - Ground
Inputs to CPDLC ground training programs		WJHTC - Ground
Input to flight deck training and handbook bulletins	AFS-400	WJHTC – Flight Deck
Optimization recommendations for American Airlines avionics and other airlines	AFS-400 and AIR-130	NASA
Recommended usability testing for any avionics system	AFS-400 and AIR-130	MITRE
Data link avionics buyers guide	AIR-130	NASA

In response to STARS report recommendation 3: *Establish technical liaison positions within NATCA, PASS, and pilot organizations (ALPA, IFALPA, APA) to provide union involvement at appropriate points in the development cycle*

CPDLC technical liaison positions with NATCA, PASS, ALPA and IFALPA have already been established. One will be established with APA.

In response to STARS report recommendation 4: *Establish mechanism to allocate and manage human factors activities*

The CPDLC human factors lead will work with the FAA Aeronautical Data Link Integrated Product Team, the FAA Human Factors Office, the avionics and aircraft manufacturers, and the airlines to coordinate human factors activities.

In response to STARS report recommendation 5: *Establish a mechanism and implementation plan to ensure that human factors recommendations are acted on in a timely manner*

The CPDLC human factors lead will meet with the core-working group to track human factors activities and assess status. This roadmap will be used as a tracking mechanism.

Section 6

Future Human Factors Activities

This section outlines human factors activities that will follow the ATSS/pilot/system interaction demonstration in December of 2000. As mentioned in Section 4, further validation of human factors aspects related to CPDLC production system components that were not available in time for the December 2000 demonstration will be required. A product of the initial (12/00) demonstration will be the identification of human factors concerns that were not fully addressed in the demonstration. Procedures to address these concerns should be incorporated into the operational test activities that will occur in late 2001.

The human factors working group also recommends that a timely and structured human factors research and engineering process be established to mitigate risks associated with future CPDLC Builds. This process starts with an update of HF factors requirements. Next, iterative controller and flight deck HCI test and evaluation activities are conducted. This is followed by ATSS/pilot/system interaction test and evaluation. In the ATSS/pilot/system interaction tests performance–oriented data are collected. These results should be compared with the human-system performance benchmark established in the initial demonstration to document improvements made throughout the human factors process as well as any operational improvements resulting from additional CPDLC capabilities.

The human factors process should also be refined based on any lessons learned from the initial roadmap activities. The CPDLC human factors lead should task the human factors working group to develop a timeline for future Builds. Given the current CPDLC implementation schedule, work should begin soon on CPDLC Build 2 controller and flight deck HCI prototypes.

Over the long term, the goal of the aeronautical data link system is to facilitate partnership among air space users and air traffic service providers in separation and traffic management functions. To support this goal and realize navigation and surveillance benefits, future communications services will need to accommodate exchange of complex trajectory information, interface with flight deck and ground automation functions for route and conflict prediction, and operational procedures that allow users to negotiate flight paths across data link. A human factors research program should be initiated to begin developing operational concepts, information requirements, and procedures for future communications services.

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Appendix A

Review of Data-Link Simulation Studies

Summary

From a review of the simulation research, there is ample evidence that data link is a useful adjunct to voice communications from a number of perspectives. Data link improves the overall efficiency of the communications system by reducing the frequency of communications failures and consequently the number of attempts required for successful information transfer. In simulations, this effect is primarily attributable to the availability of a clearer, usable representation and a persistent, storable reference of message content, although in actual operations errors caused by noise or blocked transmissions would also be avoided, as would some message formulation and transcription/data transfer errors.

User perceptions and the performance of data link indicate that its superior precision and accuracy are generally obtained at the cost of speed in the information transfer. The research findings show that delay factors associated with message generation and transmission times account for longer total transaction times with data link than with voice. The time required for message interpretation and acknowledgment is comparable for the two media, although accuracy is improved with data link. Simulation results also reveal that, within limits, controllers and pilots can effectively adapt to the added delay by performing other tasks concurrently and adjusting the timing of their communications. Because of such adaptations, execution of ATC instructions seems to take about the same amount of time regardless of the communications medium. However, the delay factors associated with message generation appear to limit data link's utility in rapidly changing conditions, whereas transmission delays limit its utility for time-critical instructions.

The simulation research clearly documents the redistribution in controller and pilot workload that accompanies data link communications: visual and manual workload increase, whereas auditory and speech workload decrease. This redistribution takes on operational significance in specific environments and for specific classes of information. In environments where severe frequency congestion currently exists, the controller's auditory and speech workload can reach an overload state. In such environments, data link helps to achieve more timely performance within acceptable workload limits by providing an additional channel for message generation and transmission, especially for repetitive messages issued to each aircraft. Conversely, the pilot's visual and manual resources are already heavily loaded in some environments. In these situations, data link increases perceived workload and could inappropriately interrupt and disrupt visual scanning and flight management tasks.

Greater consistency in procedures and message content along with display flexibility are important advantages of data link. Although the data link system inherently supports greater procedural consistency in the ATC flight deck segment of the transfer, the silent communication process requires extra measures, such as cockpit and controller team coordination procedures, voice generation technology, and display layouts, that ensure access and understanding of information by multiple operators. The research further shows that redundant display formats widen the band of information available and improve the user's access to the particular features and data that are most compatible with the mental representation of the situation and task requirements. Operationally, both analytic and holistic processing of information are combined in many of the user's tasks (Wickens, 1984, p. 121). The simulation research highlights some specific classes of information, such as weather, traffic, and route, that are most likely to show benefits of more efficient and accurate assimilation when presented in spatially oriented, graphical formats.

Taken as a whole, the research indicates that data link allows controllers and pilots to devote more attention to critical communications functions such as interpreting, evaluating, and formulating messages. It does this by offering them relief from many of the overhead functions, such as repetitive message preparation, transcription of data to preserve information for future reference, and entry of data to provide input to other systems. The ability to automate these overhead functions while retaining human involvement in critical functions not only yields greater efficiency in operations by eliminating redundant transcription and data entry tasks; it also has great potential for preventing data entry errors, and when coupled with flexible display formatting it should reduce the opportunity for errors of interpretation.

Introduction

For decades, operational use of data link has been the subject of simulation studies (Kerns, 1991; 1994). The vast majority of the research conducted to date has focused on initial use of data link for controller-pilot communications. Approaching the problem from both controller and pilot perspectives, these separate but similar studies have already produced consistent findings that have been captured in human factors recommendations and requirements documents for data link systems (Human Factors Task Force, 1992; Society of Automotive Engineers [SAE], 1994; 1996). The following sections summarize the simulation results in terms of system-level effects that obtain across specific applications and operating environments and design-dependent effects that illustrate how features of the procedures, user-system interface, and application influence data-link effectiveness.

ATC System-Level Effects

Communications Efficiency.

Congestion on the voice radio frequency has been related to a number of information transfer problems (Lee, 1989b). One of the measures used to estimate the impact of data link on frequency congestion is the amount of time controllers spend in voice communication tasks when data link is available. Talotta, et al. (1990) looked at how much time controllers spent on the voice channel under three levels of data-link equipage. In this study, enroute controllers used data link to issue radio frequencies and altitude assignments; other communications were conducted via voice, regardless of aircraft equipage. Relative to a voice communications baseline, this study found a 28% reduction in controller time spent on the voice channel when 20% of the aircraft under control were data-link equipped and a 45% reduction when 70% of the aircraft were equipped. Off-loading routine communications to the data link not only creates additional capacity on the voice channel to encourage better procedural discipline (full readbacks) but also reduces the possibility of missed or blocked transmissions.

Comparable reductions in radio frequency utilization were also reported for terminal controllers (Blassic and Kerns, 1990; Talotta, et al., 1992a, 1992b). Again, reductions were a function of data-link equipage in the traffic scenario. In two recent studies that simulated highly congested en route and terminal environments (Data Link Benefits Study Team, 1995, 1996) the results indicated that voice radio usage by controllers dropped dramatically as data link equipage reached 90% of the air traffic. Controllers reduced voice channel usage by as much as 84% in en route airspace and by as much as 70% in the terminal airspace. In addition, the studies showed that controllers continued to use data link as traffic density and volume increased.

For equivalent scenarios, study results also show that a dual-media voice and data-link system requires fewer total transmissions than an all voice system. Three studies (Blassic and Kerns, 1990; Hinton and Lohr, 1988; Talotta, et al., 1990) compared transaction counts in scenarios with and without data-link. Hinton and Lohr (1988) found that with increasing levels of data-link capability in the aircraft the number of data-link transmissions did not increase as rapidly as voice transmissions decreased for comparable flight scenarios. Consistent with this finding are data reported by Talotta, et al. (1990). This study found an overall decrease in total voice and data-link transmissions with increasing levels of data-link equipage in the traffic. Again, the drop in voice transmissions that was observed as data-link equipage increased was greater than the increase in data-link transmissions.

Blassic and Kerns (1990) produced similar results in a terminal environment simulation in which data link was used to transmit messages containing terminal information and expected approach procedures and for repetitively used ATC instructions. They compared the number of instructions issued in voice-only and data-link conditions. Compared to voice baseline, the number of instructions fell by 8.5% when 30% of the aircraft were data-link equipped and by 12% when 80% of the aircraft were equipped. All three studies attributed the reduction in total transmissions to fewer missed calls and fewer repetitions of information. Results from several studies supported this attribution (Data Link Benefits Study Team, 1995, 1996; Knox and Scanlon, 1991; Lozito, McGann and Corker, 1993). These studies found that use of data link for routine ATC messages in conjunction with voice radio as a backup and for nonroutine communications resulted in fewer messages to correct, repeat, or clarify a clearance as compared to the voice-only baseline.

From the flight crew perspective, there is additional evidence of time efficiency with data link as compared to voice communication. Talotta, et al. (1990) and Uckerman and Radke (1983) compared the total time spent by flight crews on communication tasks using voice and using data link. Both studies found that time for crews to process messages was somewhat shorter with data link than with voice. When the data-link system is interfaced to flight management functions of the aircraft, the time savings is even more pronounced. Waller (1992) and Knox and Scanlon (1991) compared time required to receive and enter data into the subsystems of the airplane using voice communication and using a data-link system that allowed the crew to transfer data directly into the airplane flight guidance system or the FMS without reentering the information. Both studies demonstrated a substantial time savings for the crew when using the data-link communication process.

Speed and Timing of Communications.

The simulation literature documents a marked difference in the speed and timing of communications when data link is used as compared to voice. These studies indicate that both total transaction time and the timing of specific events in the communication process are altered.

Total transaction time represents the entire time span when the controller would be concerned with a given communication. With a data-link system, it includes the inherent transmission delays, uplink and downlink, and the time required for a crew response. Simulation results indicate that, on average, total transaction time was twice as long for data link as it was for voice. In an enroute simulation, Talotta, et al. (1990) estimated an average total transaction time of 21 sec for data link as compared to 10 sec for voice, whereas Waller and Lohr (1989) estimated an average total transaction time of 19 sec for data link and 8 sec for voice based on a full-mission simulation.

Data taken from the terminal controller's perspective confirmed that the viability of data link in the terminal environment will depend on total transaction time (Talotta, et al., 1992a, 1992b). The 1992 study showed that as total data-link transaction time increased up to an average of 37 sec, controllers reverted to the voice channel. The final control sectors were most sensitive to longer delays. Aggregating across a set of subjective and objective problem indicators measured in the study, the investigators suggested that transactions times in excess of 22 sec would seriously limit the usability of data link in the departure and final approach sectors. Communication strategies also changed as a function of transaction time. Results showed that departure controllers, faced with increasing but not unworkable delays, tended to issue more complex messages, messages containing two or more instructions.

Data from several studies consistently estimate an average delay of 10 sec for crews to access and respond to a data-link message (Kerns, 1991), a performance that is comparable to estimates of processing times for crews to listen and respond to a voice message (Cardosi and Boole, 1991). The data link simulations also suggest a relationship between flight phase and crew response time. Two studies (Diehl, 1975; Waller and Lohr, 1989) found that crew response times tended to be shorter and less variable during the arrival phase as compared to the enroute and departure phases. Similarly, Van Gent, et al. (1994) found that crew response times decreased significantly from the oceanic through the cruise and descent phases. In this study, the results also suggest that longer message lengths in the oceanic and cruise phases may partially account for the differences in response times.

Other findings consistently reported in the literature indicate that although the sequence of procedural steps in the flight deck communication process is altered with data link, controllers will not necessarily be aware of the change because the timing of the execution of instructions is comparable for data link and voice. In simulations with both single-pilot and two-pilot crews, pilots initiated maneuvers to comply with an instruction before a response was dispatched to the controller (Hinton and Lohr, 1988; Parker, Duffy, and Christenson, 1981; Rehman and Mogford, 1994; Waller and Lohr, 1989). However, even with the changed sequence of steps on the flight deck, results from Rehman and Mogford (1994) suggest that controllers would not necessarily perceive any difference because they received a display of the pilot's data-link response before any path change was evident on their situation display. Findings from Lozito, et al. (1993) further indicate that the time required to complete execution of ATC instructions did not differ significantly for voice and data-link crews.

Evidence from controller simulations suggests that they too are altering the sequence of procedural steps for communications with data link. With voice communications, controllers are required to obtain readbacks or some other acknowledgment from the pilot. With data link, Talotta, et al. (1990) and Blassic and Kerns (1990) observed that controllers did not wait for a display indication of crew acknowledgment before issuing subsequent instructions or performing other tasks. Similarly, when Rossiter, Wiseman, Connolly, and Morgan (1975) evaluated a control-by-approval mode of messages transmission, in which the controller initiated transmission of computer-generated messages, they found that controllers did not wait for crew acknowledgment before beginning to process the next instruction.

Workload.

Across the entire body of simulation studies, there is little evidence of impacts on overall controller or pilot workload as a result of using data link. The evidence on workload shows, however, that the visual mode of information presentation and the delay performance of the communication system can result in measurable shifts in controller and pilot workload.

A general effect of data link documented in the simulation studies is a redistribution of workload: Visual and manual workload increase, whereas auditory and speech workload decrease. Groce and Boucek (1987) documented an impact of data link on copilot visual task load as a result of data link and a minimal impact on pilot visual tasking. For the copilot this increase was largely offset by a corresponding decrease in auditory task load as a result of decreased radio transmissions. The minimal increase in pilot visual tasking noted in this study tended to reach an overload state for brief intervals when monitoring of data-link information overlaid the normal instrument scanning tasks. Perceived workload data from Waller and Lohr (1989) support the same pattern of effects. When operating in the copilot role and therefore handling ATC communications, crewmembers reported a reduction in workload with data link. But when operating in the pilot role crewmember ratings of workload were mixed. Pilots with more experience reported reduced workload with data link, whereas pilots with less experience reported increased workload.

A study by Talotta, et al. (1992a) that investigated the effect of delay performance of data link found that controller estimates of perceived workload in the terminal environment increased as a function of increasing delays in data-link test conditions. Delays in excess of an average 22 sec total transaction times produced a significantly higher level of workload when compared to voice.

Although the reduction in controller speech task load is well documented in the literature (Blassic and Kerns, 1990; Talotta, et al., 1990, 1992a, 1992b), a corresponding increase in controller visual and manual workload as a result of the visual mode of communications has not been measured. It is interesting to speculate that the absence of an increase in perceived workload could mean that controller's visual channel is not yet at capacity.

Implications of Party-Line Information.

In the voice communication environment, pilots use information overheard on the common radio frequency to develop their understanding and a representation of the current operating environment. Because some information will be discretely addressed with data link and therefore not available to all users operating in an airspace, researchers have undertaken to (a) characterize important party-line information elements, (b) analyze the role of this information in pilot decision making, and (c) develop implications for application of data link.

Two studies were conducted to identify important party-line information elements and assess their accuracy and relevance to specific flight operations (Midkiff and Hansman, 1993; Pritchett and Hansman, 1994). Both studies surveyed pilots and found that specific information elements related to traffic and weather were rated as critical. Although pilots rated party-line information as highly important, they perceived it to be only moderately available and accurate (Pritchett and Hansman, 1994). Survey results also indicated that the importance of party-line information appeared to be greatest for operations near or on the airport. However, in a related simulation experiment to investigate pilot use of party-line information Midkiff and Hansman (1993) found that the ability to assimilate and use party-line information was lowest during high-workload periods. This result indicates that the party-line monitoring task may be shed in high-workload situations. It also suggests that party line does not constitute a reliable mechanism for delivering critical information.

Simulation results also recommend use of alternative means of information transfer and presentation to enhance or replace party-line information as a source of weather and traffic information. Weather and traffic information are spatially oriented data, accessed simultaneously by multiple users, and may be transferred more effectively via data-link broadcast media and presented in a graphical display format. Studies by Lee (1991) and Wanke and Hansman (1990) investigated a graphical format for presentation of wind shear information. Results of both studies showed that graphical displays improved avoidance of wind shear by pilots when compared to a voice presentation. Lee also found that flight crews provided only with conventional ATC transmission of weather information had difficulty discriminating conditions conducive to microburst events from less hazardous wind shear events and that real-time updates of the data-linked information contributed to improved situation awareness for microburst events.

Traffic information is already being provided to air carrier aircraft as part of the traffic advisory and collision avoidance system (TCAS); however, not all TCASs contain a graphical display showing the positions of proximate air traffic. Currently, the FAA is developing a lower cost version of a traffic information display for general aviation aircraft (FAA, 1994b). Future TCAS implementations will likely evolve toward a standard configuration that includes a graphical format.

Design-Dependent Effects

Operational Communications, Flight Crew, and Controller Procedures.

The relative utility of alternative protocols for conducting the controller-pilot communications dialogue via data link has been examined in several studies. Talotta, et al. (1988) investigated use of data link as a confirmation of voice transactions, whereas Cox (1988) reported on use of data link as a prenotification of a voice transaction. Other studies used data link to replace voice transactions. Overall, the simulation results generally favor protocols that minimize switching between media to complete a specific transaction (Kerns, 1991).

The difficulty in synchronizing the timing of the two media has led pilots (Cox, 1988; Eurocontrol, 1986; Hinton and Lohr, 1988) and controllers (Talotta, et al., 1988) to judge cross-media protocols as unnecessarily complex. Instead, the study results recommend that data link be used to replace selected voice communications. The findings also support consistency between procedures used in conducting communications over the two media (Kerns, 1991). More specifically, the research indicates that like voice communication procedures, data-link communication will require controller and pilot operational acknowledgment of clearance requests and ATC instructions to assure that communication is taking place correctly (Talotta, et al., 1988).

Although standard communication protocols and phraseology can be assured through automated procedures in a data-link communication environment, the addition of this medium also allows for flight crew and controller team responsibilities and procedures to be altered. Traditionally, procedures for two pilot crews assign responsibility for handling ATC communications to the copilot or pilot not flying. However, in the voice radio environment, both crew members monitor the radio frequency and simultaneously have access to messages. With data link there will be a need to develop new procedures that provide feedback to the pilot flying and thereby ensure mutual understanding of information.

Research results on two-pilot crews have recommended a data-link procedure that requires a verbal communication between pilots before responding to a data-link message (Hahn and Hansman, 1992; Lee, 1989a; Lozito, et al., 1993; Waller and Lohr, 1989). Speech generation technology has also been investigated as a mechanism for ensuring crew understanding of data-link messages, and this work is discussed in the following section. Furthermore, a recent study of pilot procedures highlights the need for new procedures in a dual media communications environment. In this study McGann, Morrow, Rodvold, and Mackintosh (in press) found that a single pilot adapted voice communication procedures to be compatible with the sequential nature of data link thus causing voice performance to deteriorate in the dual media environment relative to the voice-only environment.

Data link may also enable some alternative allocations of responsibility and changes in controller team procedures. The availability of a second communication link will permit an assistant controller to take on some of the communications tasks during busy periods. A study by Talotta, et al. (1992) compared data-link effectiveness with single-controller and two-controller teams operating combined approach and final control positions in terminal airspace. In this study, controller teams devised alternative strategies for allocating responsibilities. A prototypical allocation of responsibilities observed in the study was that the assistant controller used data link to issue instructions to aircraft on entry into the airspace and at outer fixes, whereas the primary controller used voice and handled turns to final and approach clearances.

Controller ratings indicated that a team was judged as being capable of producing higher overall capacity than a single controller at the combined sector. Controllers also reported that the two-controller team was capable of increasing capacity only when voice communication was supplemented by data link. Results from a later study in which the terminal radar controller received assistance from a supervisor or handoff controller, confirmed that the control team can successfully share tasks and increase sector capacity when data link is used to permit simultaneous communication with multiple aircraft (Data Link Benefits Study Team, 1996).

Similarly, research on enroute operations (Data Link Benefits Study Team, 1995; Shingledecker and Darby, 1995) examined how changes in the allocation of controller team responsibilities affected sector capacity. Study results showed that when teams of three controllers used a combined data link and voice radio communication system they were able to provide ATC services that improved en route sector efficiency and productivity. These effects were reflected in reduced aircraft ground delay, flight time, and flight distance in comparison to the current operational environment using only voice communications. Data on the duties and tasks of each control position showed that the addition of data link not only resulted in a shift in the distribution of air-ground communication tasks among controllers it also produced a shift in responsibilities in other sector tasks. While the radar controllers continued to perform all voice radio communications, the two assistant controllers, the data controller and the tracker, sent data link messages.

Along with the data link communications tasks, the assistant controllers also took increased responsibility for monitoring the traffic situation and making control decisions. Moreover, as the level of workload sharing increased on a variety of sector tasks, the radar controllers were able to devote more time to overseeing and directing the team's activities. Under voice-only conditions sharing of planning and decision making tasks with the assistant controllers is limited largely because the radar controller is heavily occupied by communications responsibilities. The radar position's significant involvement with aircraft communications tasks tends to hinder interactions required for team direction. Under data link conditions, the radar controllers reported a higher frequency of directing the team's actions and all three positions reported a greater level of team interaction.

User-System Interaction.

An earlier review of the simulation literature (Kerns, 1991), observed that most of the researchers had tended to investigate display/control capabilities related to one side of the (two-way) communication process, depending on their operational perspective. Controller-oriented studies focused on capabilities for generating and sending outbound messages and on the design of display feedback to permit monitoring the progress of information exchanges. Alternatively, pilot-oriented studies focused on capabilities for display of received messages and for generating responses. Considerable progress has been made since that review to develop design philosophies and principles for two-way message handling for controllers and pilots. Many of the design principles have general applicability to both controller and pilot work environments; others address unique flight deck or controller operational requirements.

Automation

The level of automation to be applied in designing data-link message sending and receiving functions has received a good deal of attention in the literature. Controller-oriented studies manipulated levels of automation in message generation and sending (Rossiter, et al., 1975; Talotta, et al., 1988, 1989, 1992b). Results of these studies indicated that controllers should retain manual control over the transmission of data-link messages and that receipt of pilot acknowledgments should automatically update the ground-system database.

For both controllers and pilots, message composition appears to work best when it is computer assisted. Menu-driven message composition has been the most widely implemented interface style in controller and pilot simulations (see Fig. 21.2 and 21.3). Users build messages by selecting from a menu of predefined messages and message elements that have been stored in their data-link system. Although alternative mechanisms for message composition will be needed in exceptional situations, simulation research suggests that considerable input error potential exists when controllers compose messages using less automated styles such as command entries (Blassic and Kerns, 1990; Talotta, et al., 1992b).

A key automation issue for the flight deck system design concerns the use of automatic versus crew actions to acknowledge messages and transfer message data to other aircraft subsystems. Pilot-oriented simulations have examined alternative levels of automation and crew procedures in this process. Waller (1992) evaluated a semiautomatic process that allowed the pilot to acknowledge the message to ATC and copy the data into a standby area of the data-link display. A second action was then required to copy data to the appropriate flight subsystem. Results from this study indicated that allowing the pilot to transfer data directly from the data-link system to flight management functions without reentry of the information was highly beneficial as long as the flight crew remained in control of data input into the subsystems of the airplane.

At the same time, the study pilots also recommended that certain messages such as radio frequency assignments should only require a single input to dispatch an acknowledge and transfer the data. Knox and Scanlon (1991) compared "Roger" and "Roger/Enter" options that either dispatched a response to ATC or dispatched the response and inserted data into the airplane's flight control or flight management system. In this study, the combined

Roger/Enter option was used 86% of the time for tactical messages, and results suggested that the single-input transfer process greatly reduced crew workload.

Hahn and Hansman (1992) also used a semiautomatic process and obtained similar results when they compared automated FMS programming of data-linked clearances with manual FMS programming of data-link and voice clearances. Their findings indicate that crews were better able to detect errors in messages with the use of automated FMS programming. Crew comments noted that the automated programming allowed them to focus their time and effort on the highest level of interpretation; rather than focusing on isolated words and numbers.

In the Knox and Scanlon (1991) study, several crews suggested that they would have liked the option to transfer data to the FMS as provisional modifications prior to dispatching a response to ATC. Lozito, et al. (1993) examined a message preview and direct entry option. In the simulated data-link interface, it was possible for the pilot to automatically load information from the message before or after dispatching an acknowledgment. If the pilot previewed and directly entered message data into an aircraft subsystem, the data-link system would automatically send an acknowledgment. The pilot could also elect to acknowledge the message without first exercising the preview and direct entry option. This study reported longer response times than those previously found in simulations. A mean acknowledgment time of about 21 sec was observed for data-link messages, over twice as long as the average 10 sec response times observed in previous studies. Longer response times notwithstanding, data-link crews in this study had fewer communications errors, performed more concurrent tasks, and took the same amount of time to comply with the messages when compared to the voice crews.

Display Surfaces and Locations.

Determining the best display surfaces and locations for supporting data-link functions in the controller workstation and the cockpit has been the subject of several simulations. Controller-oriented simulations (Rossiter, et al., 1975; Talotta, et al., 1988, 1989) evaluated the desirability of integrating data-link message data with aircraft data tags on the situation display as compared to grouping all message and transaction data in lists. Results consistently indicate that the integrated presentation is most efficient for controller monitoring of data link transactions, but that dedicated lists of active and completed data link transactions are also desirable as redundant displays.

Pilot-oriented simulations (Rehman and Mogford, 1994; Van Gent, Bohnen, and Jorna, 1994) evaluated alternative display locations comparing forward- and aft- mounted data link displays. Not surprisingly, the forward-mounted display locations resulted in shorter response times. When data link shared a display with other flight management functions, this too resulted in shorter crew response times compared to a dedicated data-link display (Van Gent, et al., 1994).

Display Modes and Formats.

The benefits and drawbacks of alternative display modes and formats, including speech, graphics and textual presentations, have been investigated in a number of flight deck studies (Diehl, 1975; Hahn and Hansman, 1992; Hilborne, 1975; Lee, 1991; Rehman and Mogford, 1994; Waller, 1992). Overall, the results of these investigations favor redundant presentations of information such as text with speech and text with graphics. At a minimum, a textual format appears to be required for presentation of most messages. However, the addition of speech and graphical formats enhances individual and team comprehension of messages by allowing human access through multiple attentional resources and at multiple levels of message interpretation.

Audio annunciation of data-link messages using speech generation technology has been investigated in a number of flight deck simulation studies (Diehl, 1975; Groce and Boucek, 1987; Hilborne, 1975; Rehman and Mogford, 1994; Waller, 1992). This presentation technique has promise for offsetting some of the added demand data link places on the crew's visual and manual processing resources and for supporting crew coordination in a data-link environment. The findings consistently show that (a) flight crews judge speech output to be desirable as a redundant display option for data link messages, but (b) the addition of speech output increases crew response times substantially when compared to visual displays alone. Related research has also shown that comprehension of spoken messages takes longer than reading text of a similar complexity, with the amount of time increasing as a function of decreasing speech quality (Baber, cited in Stanton, 1993).

A number of design and procedural issues were also noted in the research results. Speech output can be very intrusive, and can disrupt current task activity. Specifically, it was noted that automatic activation of speech output can disrupt flight crew tasks. Even with a manual control, in order to allow both crew members to orient themselves, the speech presentation should be preceded with a sound or phrase, as is the case with current voice communications from controllers to pilots, which start with a callsign. Some studies also reported crew problems because of speech rate and quality. Research on comprehension of synthetic speech indicates that human listeners focus more attention at lower levels of interpretation, such as isolated words, when quality is poor and therefore have less spare capacity for understanding the intent of the message (Pisoni, Nusbaum, and Greene, 1985; Baber, cited in Stanton, 1993). However, the additional processing demand and cognitive effort imposed by synthetic speech can be decreased with training and practice. Perhaps the most critical design issue identified in these studies is the potential for speech output to interfere with concurrent voice communications on the ATC radio frequency.

Graphical and textual display formats have also been compared to voice presentations (see Fig. 21.4 for examples of a graphical display formats). Hahn and Hansman (1992) found that a graphical presentation of data-link message improved the ability of crews to detect errors in clearances when compared to a textual or voice presentation. The advantage was most pronounced for detection of erroneous clearances into weather. Despite the improved error detection performance with the graphical format, flight crews in this study felt that a combined textual and graphical presentation was desired to support the full range of decision tasks (e.g., strategic evaluation, extraction of detailed flight parameters) that are required for compliance with clearances. Like the improved listening comprehension that results from higher quality speech, this study suggests that graphical format allowed the crew to focus attention at a strategic level. Results from Lee (1991) and Wanke and Hansman (1990) also support the advantage of graphical formats for presentation of weather information.

Data Link Applications.

According to the research, successful application of data link to ATC/flight deck information exchanges depends on the operating environment in which the exchange occurs and the type of information contained in the message. Fig. 21.5 depicts the areas that controller - and pilot-oriented research has identified as suitable for data-link application (Kerns, 1991). As the figure shows, data link is generally more acceptable in less busy operational environments and flight phases, such as predeparture and enroute.

In the terminal environment, pilots and controllers have long expressed cautions and reservations over use of data link, although until recently simulation research in the terminal environment was limited (Kerns, 1991). Early studies of data link reported that pilots judged most applications related to local and ground control functions unacceptable for data link. The landing clearance was deemed acceptable as a data-link instruction, depending on when it was given (Hilborne, 1975; Hinton and Lohr, 1988). More recently, controller-oriented simulation studies have begun to fill in more of the details concerning the types of messages that are acceptable and to establish the boundaries of the operational envelope for using data link in the current terminal environment. These studies suggest that data link is most appropriate for longer, repetitive messages, such as routine information on terminal operating conditions and expected approach procedures, which tie up the voice channel (Blassic and Kerns, 1990; Talotta, et al., 1992a). Results also indicate that in general, data link would not be suitable for time-critical instructions, such as turning aircraft onto final or dealing with missed approaches (Talotta, et al., 1992b). Thus, it appears that the timing of message delivery is a driving factor for data-link use during approach operations. Messages that can be prepared and issued in advance of final approach and landing operations should be acceptable for data link in terminal airspace.

Early operational experience with data link in the predeparture environment has also been instructive in the design of data link applications. Since 1991, the FAA and several airlines have been using a data link to alleviate severe congestion problems on clearance delivery frequencies and to improve the transfer of involved, often lengthy predeparture clearance (PDC) instructions to pilots. Controllers issue PDC's digitally to participating airlines through the airline communications network. In turn, the airline dispatch office has responsibility for actual delivery of PDC's to flight crews, typically using the company data link and a cockpit display or printer. This first operational experience with digital PDC's received broad support from the participants (Moody, 1990); it also served to document some of the weaknesses in the indirect method of controller pilot communication and highlighted a number of human factors issues associated with data-link communications (Drew, 1994). Incident reports on PDC cite procedural deviations in which crews failed to obtain their PDC or received the wrong PDC. Under the current PDC delivery system, voice communications are used to verify that the PDC has been issued correctly; however, this procedure is not standard across airports. Another class of incidents relates to problems in interpreting the PDC information. These reports indicate that crews have difficulty interpreting some cockpit display formats used for PDC. They cannot find critical information quickly and accurately, and they cannot easily detect changes in their usual routes.

On balance, the advantages of a digital PDC in terms of reduced frequency congestion and a clearer, persistent visual presentation of messages outweigh the drawbacks in terms of the limited feedback to verify clearance delivery and the display formatting problems in the initial system. This has encouraged the FAA and the airlines to begin experimenting with a digital automatic terminal information service (ATIS) (Kuhl and Berry, 1989). The ATIS is also a lengthy, involved message. Controllers, working in airport traffic control towers, record the ATIS and broadcast it continuously over dedicated radio frequencies. It gives local weather conditions, runways in use, and other airport advisories. Pilots are required to listen to the ATIS during approach to and before departure from an airport.

A field evaluation of a prototype digital ATIS application conducted at two airports produced uniformly positive responses from pilots, although controllers identified a number of required enhancements for the system they used to generate the ATIS (Aeronautical Radio, 1992). Flight crew comments indicated that a digital ATIS afforded them greater flexibility to plan approaches early and improved message clarity over the voice broadcast. On the other hand, controllers found that the initial system placed a significant demand on them to coordinate the dual tasks of composing the text version and recording the voice version of the ATIS. As a result, the digital ATIS application was modified to incorporate speech generation technology and allow the controller to create text and voice messages with a single procedure.

Apart from considerations of the operating environment, there appears to be an intrinsic advantage in applying data link to the transfer of weather information because of the graphical formatting capability (Lee, 1991; Wanke, Chandra, Hansman, and Bussolari, 1990; Wanke and Hansman, 1990). Although the graphical format is undoubtedly the most efficient means for representing this information, the time criticality of bringing hazardous weather situations to the crew's attention also places stringent demands on transmission system performance and crew alerting capabilities. Moreover, operational issues associated with controller awareness of and responsibility for delivery of hazardous weather advisories as well as verification of the crews' intent following notification have yet to be resolved.

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Appendix C

CPDLC Integrated Schedule